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THE PLACE OF ENERGY GRASS ‘SZARVASI-1’ IN RENEWABLE ENERGY GENERATION

PhD thesis

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1. Background – topicality of the subject

Energy is essential for life but especially for development and improvement. When we talk about energy, we usually focus on energy sources, energy uses, energy-efficiency and environmental pollution resulting from energy generation. However, fewer people are thinking about solving these problems and even fewer are doing anything about it. One prominent sign of the harmful effects is climate change resulting from the atmospheric emissions of greenhouse gases (GHGs) and land use changes.

Currently, one of the biggest fears in the world is caused by the intensification of phenomena associated with climate change. The IPPC (2007) estimated the temperature changes of the atmosphere on the basis of various factors, including growth of the global population, economic growth and GHG emissions.

Growth of the global population cannot be halted; however, by prudent steps concerning economic growth, significant results can be achieved in mitigating climate change. Thus, both global population growth and the continuous economic growth represent great challenges in relation to the use of future energy sources. Therefore, one method of reducing atmospheric emissions of GHGs, which are responsible for climate change, is increasing the use of renewable energy sources. Renewable energy sources are energy sources that are constantly in the course of natural processes, or regenerate within not more than a few years without significant human intervention.

Hungary is one of the least energy-efficient countries, and is able to utilise the available renewable energy sources only at a rather low level. Encouraging the use of renewable energy sources may assist in reducing the import dependence, in enhancing the safety of energy generation, and in diminishing the negative environmental impacts resulting from the use of fossil fuels.

In terms of sustainable development, the demand for renewable energy sources including biofuels is on the increase, and this may strengthen the energy generation character of agriculture. Such structural changes are associated with numerous advantages, and are particularly important for Hungary – a country poor in fossil energy carriers but with relatively favourable agricultural characteristics (SIPOS, 2006). Attractive alternatives include renewable energy sources such as biomass, since biomass is available in sufficient quantities and quality in Hungary.

2. Objectives of the present dissertation

In summary, the objective of this study is to analyse the use of environment-friendly biogas as biofuel. In addition to addressing traditional renewable energy sources and feedstocks thereof, this research covers alternative feedstocks that would ensure revenues for the rural populations, improve the quality of life, and solve environmental problems.

I have defined the field of research for this dissertation accordingly. In this paper, I am seeking answers in relation to the potential of using biomass feedstocks, while also taking into account economic, political, food and feed safety, and environmental and energy safety considerations. In the framework of a comparative study, I wished to point out the future advantages and disadvantages of biofuels such as first-generation bioethanol and biodiesel, and biogas. Since one of the key objectives of this research is to explore the utility and economic viability issues of the fuel obtainable from biogas, i.e., biomethane, it was an important aspect to describe the existing and potential agricultural feedstocks of biomethane production. I also conducted a detailed analysis of energy grass 'Szarvasi-1' and its future use as a feedstock of biogas production, and compared it to the typical values of the currently applied silo maize in terms of methane output and dry matter contents.

The main direction of this research is defined by answering the following questions:

- should we consider renewable energy generation and energy uses within the transport sector, i.e., is it possible to efficiently replace fossil fuels in the short, medium and long term?
- what biofuels obtainable from commercially available biomass are currently available, and their comparison in terms of feedstock, food, energy and environmental safety;
- how did biogas production develop in Europe and what are the perspectives in Hungary: can we replace the currently predominant maize feedstock with other energy crops such as energy grass 'Szarvasi-1'?
- can it be a perspective for Hungarian cities to use biomethane obtainable from biogas as fuel upon upgrading public transport?
- in addition to its uses in energy generation, is it possible to employ energy grass 'Szarvasi-1' for the active protection of the environment?

Thus, in summary, the objective of this study is to analyse the use of environment-friendly biogas as biofuel. In addition to addressing traditional renewable energy sources and feedstocks thereof, this research covers alternative feedstocks that would ensure revenues for the rural population, improve quality of life, and solve environmental problems.

Accordingly, in this paper I am seeking specific answers to the following five hypotheses:

Hypothesis 1 (H1) – Among the biofuels obtainable from biomass, the improvement and development potential of biogas exceeds the potential of bioethanol and biodiesel obtainable from first-generation food crops. Thus, more emphasis should be placed on encouraging production and use of biomethane in the future.

Hypothesis 2 (H2) – On the basis of measured biogas production characteristics, the currently popular maize (silo maize), which is the most widely used agricultural feedstock of biogas production, may not be considered as the best feedstock. There exist energy crops specifically suitable for energy generation purposes, which may enable alternative biogas production solutions without jeopardising food and feed safety.

Hypothesis 3 (H3) – In addition to satisfying the demands of the growing biogas sector, the cultivation of energy grass 'Szarvasi-1' would be profitable and competitive in comparison with the currently used maize, even without subsidisation.

Hypothesis 4 (H4) – Biomethane obtainable from biogas offers future perspective in terms of public transport in major cities.

Hypothesis 5 (H5) – Besides being used as a feedstock for biomethane production, other uses of energy grass 'Szarvasi-1' allow for the remediation of contaminated soils. This may represent a completely new direction for profitable environmental activities associated with renewable energy generation.

Materials and methods

The scientific basis of this work consists of sources cited by Hungarian and international literature. Finding the answers to the questions of this dissertation was facilitated by reviewing and systematising the international and Hungarian literature of key significance. Studying the literature of biofuels, and more specifically of biogases, not only provided an understanding of the international market, but also allowed for an exploration of domestic opportunities. This may also help getting closer to solving the current problems.

In the framework of preparing this dissertation, I assessed potential approaches to reducing the energy dependency of both Hungary and Europe through the use of biofuels, more specifically, first-generation bioethanol and biodiesel, and biogas obtainable from wastes and wastewater, while also taking into account food and feed safety, environmental safety and economic viability considerations. In connection with this, I analysed the fossil fuel dependency of the EU-27 and Hungary based on the available commercial data. Furthermore, I summarised the main expectations of the Europe 2020 Strategy regarding renewable fuels to be used in transport, as well as the related Hungarian commitments since these commitments are mandatory and non-compliance with them would entail sanctions. Therefore, these commitments will significantly influence the biofuel policy of Hungary until 2020.

The following authors and works – grouped according to key thematic areas – should be highlighted:

- Theoretical relationships related to renewable energy sources are analysed in detail by, *inter alia*, Láng, Fogarassy-Neubauer, Farkasné, Popp and Somogyi.
- The potential of biomass as a renewable energy source is discussed by Popp-Potori (ed.), Popp, Jobbágy-Bai-Juhász, Gyuricza.
- Works that contributed to the international and national evaluation of alternative fuels that can be used in transport, such as bioethanol, biodiesel and biomethane, include Somogyi, Popp-Potori (ed.), Popp-Somogyi-Bíró, Bai, Gyulai, Sipos-Somogyi, Sipos et al., Popp, Bai-Jobbágy, Hajdú, Popp-Somogyi, and Uellendhal et al.
- The fuel perspective of biogas and biomethane obtainable from it is discussed in the scientific articles by Gyuricza, Tihanyi et al., Kapros-Csete-Szunyog, Hopfner-Sixt, Kirchmayer, Pucker et al., Jobbágy-Bai-Juhász, Schumacher, Pädams et al., and Terrón. The basic data required for my calculations are from the Budapest Transport Centre (BKK), the Sewage Works of the Capital City (FCSM), and the Central Wastewater Treatment Plant of Budapest (BKSZT).
- The results of concrete studies on energy grass 'Szarvasi-1' were published by Geiβendorfer, Sipos, and Fodor-Vashegyi-Sipos.

- Cost and revenue data for the cultivation of silo maize and energy grass ’Szarvasi-1’ were provided by Pálhalmai Agrospeciál Kft. (Pálhalmai Agrospecial Ltd), and Bikazugi Mezőgazdasági Nonprofit Kft. (Bikazugi Agricultural Nonprofit Ltd).
- In the framework of this complex biogas research effort, I sought to process basic data from the following Hungarian and international institutions: Agro-Economic Research Institute, Hungarian Central Statistical Office, Hungarian Biogas Association, Hungarian Energy Agency, as well as Eurostat, FAO, US Department for Agriculture, Environmental Protection Agency, European Biomass Association, Technische Universität Vienna, European Biodiesel Board, Landwirtschaftlichen Lehranstalten, Bikazugi Mezőgazdasági Nonprofit Kft. (Bikazugi Agricultural Nonprofit Ltd), and the Department of Plant Physiology and Moelcular Plant Biology of Eötvös Lóránd University of Sciences.

In addition to the basic sources of literature, further information was provided by journals, studies and various working papers addressing the topic in the narrower or broader sense. It is worth underlining the journals *F.O.Licht*, *Environmental Impact Assessment Review*, *Natural Resources Research* and *AgraFacts* among the international sources and *Európai Tükör, Gazdálkodás*, *Statisztikai Tükör,* and *Tudomány* among the Hungarian sources.

Further primary sources include documents published by the Commission of the European Union, the European Parliament and OECD, as well as any information obtained during professional conferences and business discussions.

Methods

As regards the place of energy grass ’Szarvasi-1’ in renewable energy generation, I tried to provide complex answers to the why, what, when, where and how questions raised in relation to the objectives of my research work. I put forward and explained the concepts to be studied in relation to sustainable development, renewable energies and biofuels.

I paid special attention to economic, environmental and social aspects that are potentially related to the expansion of biofuels and I assessed them on an international level, and analysed the basic data collected in line with the objectives of this research. When reviewing the literature of first-generation biofuels and biogas, I made comparisons, document analyses and comparative analyses, and I also systematised such literature using a PESTEL (political, economic, social, technological, environmental) analysis.

I dedicated a separate chapter to the issues related to the production of bioethanol, biodiesel and biogas, as biofuels, in terms of food, energy and environmental safety. As regards the status of these three biofuels, I provided descriptive presentations according to their role in the given field to allow me to elaborate on the necessary explanations.

I carried out a comparative analysis of four plants suitable for producing biogas (maize as reference, energy grass ’Szarvasi-1’, cup plant, and switchgrass) by summarising experimental results from dry matter content, fresh weight yield, dry weight yield, methane output and methane yield measurements.

To process and systematise the primary and secondary data when performing cost-benefit analyses (CBA) for energy grass ’Szarvasi-1’ and silo maize, I used Microsoft Excel together with formulae, indicators and reliability factors appropriate for this analysis.

When assessing the perspective of biomethane in major cities, I prepared a comparative table on European experiences in order to systematise international documents, project descriptions and project completion documents from European cities.

As regards data from Budapest, I processed secondary data and used related proportions to make estimates through extrapolation in order to establish a model.

In the framework of assessing additional potential uses of energy grass ’Szarvasi-1’, I presented results from cultivation experiments involving wastewater sludge treatment, which are published in Hungarian for the first time in this dissertation. During this experiment, wastewater sludge was used to provide energy grass ’Szarvasi-1’ with the necessary nutrients and water supply, and the disposal of the wastewater sludge was partly or fully solved at the same time. In relation to the various wastewater sludges generated as end products of the three most typical wastewater sludge treatment technologies, a separate study focussed on monitoring and analysing the differences achieved in mycorrhiza-treated containers. Criteria included whether the tolerance of the plant to specific components of the wastewater sludge improved in the treated area, whether its vigour (biomass production) became more intensive, and whether its accumulation capacity increased.
The considerations of the research regarding the cultivation of energy grass ’Szarvasi-1’ on soil samples treated with various wastewater sludges – using three types of wastewater sludge, in case of seeding with or without mycorrhiza treatment, as compared to mycorrhiza-treated and non-treated reference areas cultivated using traditional soil fertilisation – included :

- Heavy metals and other pollutants remaining in the soil after nutrient uptake by the plant.
- Assessment of the tolerance and physiological parameters of the plant.
- Assessment of the accumulation capacity of the plant.
- Combustion testing of harvested plant parts.

The cost-benefit analysis of the combination of phytoextraction and renewable energy generation – as the fifth hypothesis – is based on the results of the above-mentioned scientific experiment. I wished to prove the potential of cultivating of energy grass ’Szarvasi-1’ for combustion purposes, and the existence of an alternative solution for the wastewater sludge problems using cash flow analyses, empirical methods and estimate-based calculations.

As the managing director of Bikazugi Mezőgazdasági Nonprofit Kft. (Bikazugi Agricultural Nonprofit Ltd.), I gathered significant professional experience and knowledge, which I transposed into my PhD dissertation in an empirical manner. Moreover, this dissertation integrates the knowledge gathered during the preparation and implementation of this research, participation in international and national conferences, and from my own professional documents and presentations on energy grass ’Szarvasi-1’.

3. Results

1. During the past 20 years, global CO_2 emissions represented the biggest challenge and problem to solve in terms of sustainable development.

Approximately 87% of the energy generation and energy consumption worldwide is from energy carriers of fossil origin. Therefore, oil is extracted in the world in significant quantities, and although the reserves are predicted to be exhausted, new oil resources are being found. In the past, oil prices were determined by the oil producing and exporting countries of the Middle East, i.e., by the OPEC (Oil Producing and Exporting Countries). The dramatic increase in the world price of oil in recent years may be due to the growing energy demand of the industrial production of China and India, besides the growing demand for energy carriers. The growing demand is obviously associated with a rise in oil (and thus natural gas) prices, and this also dictates a rise in the prices of agricultural inputs, and thus outputs.
Hence, it is in our fundamental political, economic and social interest to reduce oil dependency, and to reduce CO_2 emissions through exploring and using alternative sources of energy.

2. Today, biomass is the only renewable energy source which is available in Hungary in sufficient quantities and through which the oil dependence and energy exposure of the country can be significantly reduced in view of its potential uses.

Among the renewable energy sources, water, wind and tidal energy may constitute the basis of electricity production, while solar and geothermal energy can be used to produce both electricity and heat. On the other hand, biomass is the most versatile renewable energy suitable for producing electricity and heat, as well as fuels. In 2010, only 7.39% (Hungarian Central Statistical Office, 2012) of the energy consumed in Hungary was from renewable energy sources, which is well below the European average (13.47%).

The key conclusions of my survey of renewable energy sources in Hungary may be summarised as below:

- Solar energy – which could be one of the most obvious solutions in satisfying domestic energy demands – is limited to greenhouses, agricultural dryers, and auxiliary hot water supply from solar collectors.
- In Hungary, wind energy is an attractive alternative for agricultural areas and farmers, because they can make immediate use of the energy produced since wind energy cannot be stored. The geographical conditions (development of surface, manmade structures, topography, and wind speed changes above the ground) of the country represent further problems, and entail fluctuations in wind power generation. In addition, the anomalies of the current power feed-in scheme also prevent us from building upon this renewable energy source in the long run.
- Due to various geographical and hydro-geographical, and economic reasons, the role of water energy (hydropower) in domestic energy generation is not significant. In 2012, a total of 5 major and 32 minor regional or local hydropower plants were in operation, and provided for less than 0.5% of the total domestic electricity consumption.
- Hungary has no power plants based on geothermal energy. The economic explanation for this is that it is impossible to produce electricity from geothermal energy in an economically viable manner in Hungary because heat accessible at realistic depths is

of relatively low temperature, and taking it from further depths would exponentially increase production costs.

- Today, biomass is the only renewable energy source which is available in Hungary in sufficient quantities and through which the oil dependence and energy exposure of the country can be significantly reduced in view of its potential uses, because a constantly renewing energy source can be obtained from it either directly or upon the necessary transformations.

3. When using biomass for energy generation, it should be considered that certain types of biomass compete for agricultural lands that are available in limited quantities, and exclude other uses of such lands for shorter or longer periods.

According to the basic definition, biomass is a transformed organic material produced by plants or animals. As regards their origin, biomasses can be primary, secondary or tertiary. Primary biomasses may originate from terrestrial plants and forests, and aquatic plants. Secondary biomasses include by-products and wastes of conventional agricultural produces, plants (grasses, trees and fodder plants) specifically cultivated for energy generation purposes, and main products and by-products of animal rearing (manure). Plant production and forestry produces biomass at a rate of 400% to 500% of the total invested energy. The third category of biomass includes by-products of human physiological functions (wastewater sludge) and organic by-products of the processing industries.

A key dilemma worldwide is the competition for food raw materials, in which food, feed, biofuel and environmental industries are competing with each other for the raw materials that can be produced over a unit area of land.

Table 1: Potential to replace the fossil fuel consumption of the European Union by first-generation bioethanol and biodiesel

Bioethanol feedstock	Maize growing area 2011		Total cereal (wheat, maize, rye) cultivation area sown by maize		Fossil fuel consumption	Replaceable by bioethanol
	1000 ha	1000 toe	1000 ha	1000 toe	1000 toe	%
Maize (1.5 toe/ha)	13,000	19,500	55,523	83,284.5	116,578	71.44

Biodiesel feedstock	Rape growing area 2011		Total oilseed crop (rape, sunflower, soy-bean) cultivation area sown by rape		Fossil fuel consumption	Replaceable by biodiesel
	1000 ha	1000 toe	1000 ha	1000 toe	1000 toe	%
Rape (1.2 toe/ha)	6,700	8,040	11,124	13,348.8	193,137	6.91

	Total cereal/oilseed crop cultivation area		Fossil fuel consumption	Replaceable by biofuels
	1000 ha	1000 toe	1000 toe	%
Biofuels, total	66,647	96,633.3	309,715	31.20

Source: Based on EUROSTAT, USDA-FAS and CEPM data, Own compilation, 2012

Although we are able to sustainably produce biomass in quantities that greatly exceed the food and feed demand, and significant amounts of biofuel and biogas could be produced therefrom, it can be concluded that even by sowing the arable lands in the EU-27 with biofuel feedstock we could not replace more than 32% of the fossil petrol and gasoline consumption. At the current technological level, irrational increases in the production of first-generation bioethanol and biodiesel could result in biofuel or food dependence instead of, or in addition to, oil dependence. Therefore, more efficient solutions should be identified to replace fossil fuels, and this could be ensured by biogas production.

4. **Biogas produced from biomass may represent an alternative in replacing conventional fossil fuels since biogas is the only biomass product which is not in conflict with the interests of any groups or sectors, and indeed contributes to maintaining environmental safety and to protecting the environment.**

The advantages of biogas are similar to those of compressed natural gas (CNG), which is already in use in vehicles. Additionally, the advantages of biofuels produced from wastes include:

- Enhanced energy safety – Due to its versatility, biogas is able to replace non-renewable resources such as coal, oil and natural gas, the latter being also of fossil origin. We may produce a renewable energy carrier from wastes which – unlike bioethanol and biodiesel – does not represent hazards to other sectors.
- Reduced GHG emissions – The production and use of biogas reduces the atmospheric emissions of methane, which is formed and emitted into the air during manure storage. At the same time, biogas production is able to reduce the quantities of CO_2 emitted during the use of fossil energy carriers. It should be noted that methane is 21 times as strong a GHG pollutant as carbon monoxide.
- Improved economic indicators – Through biogas production, energy is generated from wastes at almost zero feedstock costs. At the same time, the by-products of biogas production may be recovered as high value manure, and this may reduce the costs of applying artificial fertilisers.
- Cleaner environment – When producing biogas through anaerobic decomposition, the quantity of wastes and the unpleasant odour from putrefaction can be significantly reduced in comparison with aerobic composting.

5. **First-generation biofuels can be suitable for the equipment required to achieve the objectives set for 2020 even at the current technological level; however, they will not be able to cause a drastic reduction in GHG emissions. Therefore, when considering the issues related to transport policies, the limitations of the sector should also be addressed.**

In the framework of the Europe 2020 strategy, the EU has specified the objectives of sustainable development, and the strategy describes parameters to be achieved by the EU by 2020. Environmental issues, such as the mitigation of climate change play a key role in this strategy. Consequently, the EU clearly aims at establishing an almost CO_2-neutral transport system made independent from oil imports. At the same time, the oil-free transport objective may mean future electric or hydrogen fuel cell vehicles, which will require significant – and yet unforeseeable – infrastructural investments.
Since fuels (bioethanol, biodiesel or biogas) produced from biomass are suitable for powering vehicles, the EU has established a political and legal framework for biofuels. By 2020, all Member States are obliged to achieve a ratio of 10% in the energy uses by the transport sector. The specified target value is not unrealistic, and can be achieved by appropriate and prudent implementation. A mandatory level of use is favourable for biofuel production and

uses, because it means a guaranteed and predictable demand and market. Since the production of second-generation fuels is still in the pilot phase, further developments will be necessary before introducing them on an industrial scale.

Thus, when considering the issues related to transport policies, the limitations of the sector should also be addressed, because – besides the high average age of the vehicles and the reduced number of new car sales – the lack of social incentives, the lack of infrastructure encouraging the use of biofuels by consumers, and the limited technical parameters of the current internal combustion engines strongly influence the fundamental limitations.
Also taking into account the limitations of the energy consumption by the transport sector, of the reduction of GHG emissions, and of the convertibility of vehicles, due consideration should be given to the potential ways of involving public transport in achieving the target values, because the target values for 2020 may only be achieved, and the emerging problems may only be solved, in a cost-efficient manner, and through a uniform public transport system and the expansion of the use of alternative fuels (bioethanol, biogas) in public transport.

6. **Unlike "green electricity", "green gas" is not receiving state aids, although feeding biomethane into the gas supply network is impossible without such regulatory schemes ("green gas" tariff), legal background (the parameters of purified biogas) and intervention by the authorities (controlling the feed-in process).**

A legislative background and a corresponding subsidisation policy which would allow economically viable production, and use of biogas from agricultural, municipal and industrial wastes is inevitable.

The future of industrial biogas investments is encumbered by the lack of regulations and financial support, as well as by numerous administrative hindrances such as:

- the bureaucratic procedure is too complicated in Hungary,
- the authorisation procedures for biogas production plants, for connecting to the network and for feeding-in represent further difficulties in terms of developments, because permits from more than 20 authorities are required to start a biogas production plant,
- obtaining these permits from the authorities is extremely time-consuming (2 years on average),
- obtaining these permits may require major expenditure from the part of the investor, up to several million forints,
- the authorities involved in the permitting process often lack expertise regarding the practical functioning and operation of biogas production plants.

In view of the current industrial growth trends and the hindrances of development, I believe that the expansion potential of the sector is limited.

7. **The use of biogas in the form of biomethane appears to be a promising future.**

Due to their higher octane number, gas fuels do not contain anti-knock additives and can be fully mixed with the air entering the engine. The most significant advantage is that car gases contain simply hydrocarbon compounds, unlike conventional fuels. Due to the above-listed characteristics, car gases are combusted more perfectly than conventional fuels. The exhaust gas contains less carcinogenic polycyclic aromatic compounds. Furthermore, the emissions of nitrogen oxides (NO_X), carbon monoxide (CO) and hydrocarbons (CH) are lower than in petrol by 20% to 40%, 60% to 90%, and 40% to 60%, respectively. Owing to the better mixing properties of the gas and air, oil consumption is also reduced, and the intervals between oil exchanges double; as a result, less waste oil is generated.

According to our current level of knowledge, the advantages of biomethane as fuel further include:

- given that the technical parameters of compressed natural gas (CNG) and compressed biomethane (CBG) are almost identical, already existing natural gas filling stations can be used to fill biomethane,
- the fuel equivalent of biomethane is 140% of that of its fossil fuel counterpart,
- biomethane produced from feedstock produced in 1 hectare of land enables a high fuel equivalent performance,
- biomethane is able to reduce the competition for unit areas of land, thus leaving space for raw materials of food production,
- owing to its favourable combustion properties, biomethane may reduce the atmospheric emissions of nitrogen oxides and reactive hydrocarbons in comparison with fossil petrol and gasoline,
- the higher profitability of using biomethane versus fossil fuels is absolutely clear,
- the gradual expansion of biomethane-powered vehicles improves the related infrastructure and makes their use more comfortable and accessible.

Challenges of using biomethane for powering vehicles:

- Since the calorific value of gas fuels is lower, reduction of the engine performance of the vehicle is within 5% under identical circumstances. That is, more fuel is needed for the same performance, if gas is used to power the vehicle instead of petrol. This represents an increase in the consumption by 10% to 15% if expressed in litres. The extent of this extra consumption significantly depends – in both the positive and the negative direction – on the conditions of the engine, especially as regards the ignition system and driving style. Owing to its favourable price, significant operational cost savings could be achieved by the introduction of further subsidies potentially encouraging the use of car gas.
- In comparison with fossil fuels, biomethane is currently disadvantaged as a result of its undeveloped distribution system and network of filling stations,
- In the future, the existing car park needs gradual adaptation, which would make both light and heavy weight vehicles suitable for using biogas.

8. Taking into account the agro-ecological, environmental, soil use, energy generation and economic viability considerations, the agronomic, energy generation and industrial properties of energy grass ’Szarvasi-1’ are highly promising, and several aspects of it are also unique in comparison with other plants suitable for this purpose.

As a result of the agricultural policy of the European Union, agricultural production has clearly shifted towards the cultivation of COP plants (cereals, oilseeds, protein and fibre crops). However, the intervention scheme of maize and wheat was cancelled in 2010, making it understandable that there is now increasing reservation regarding the expansion of maize production.

In Hungary, one of the key agricultural feedstocks of biogas production is manure to which plant residues are admixed. Animal stocks have been reducing in number since 1990, making it impossible to increase the availability of manure feedstock to new and existing biogas plants in the future. Therefore, the constant and safe feedstock supply to existing gas production plants may be problematic. For the purpose of producing biogas in suitable quantities and quality, we could expect a rise in the amount of admixed plant-based materials in the future. Since biogas is currently produced by the addition of maize, increased demands may result in increased market prices; therefore, biogas production plants will look for energy crops, more specifically energy grasses, as alternative solutions, from which gaseous alternative energy carriers may be produced in order to reduce energy dependence.

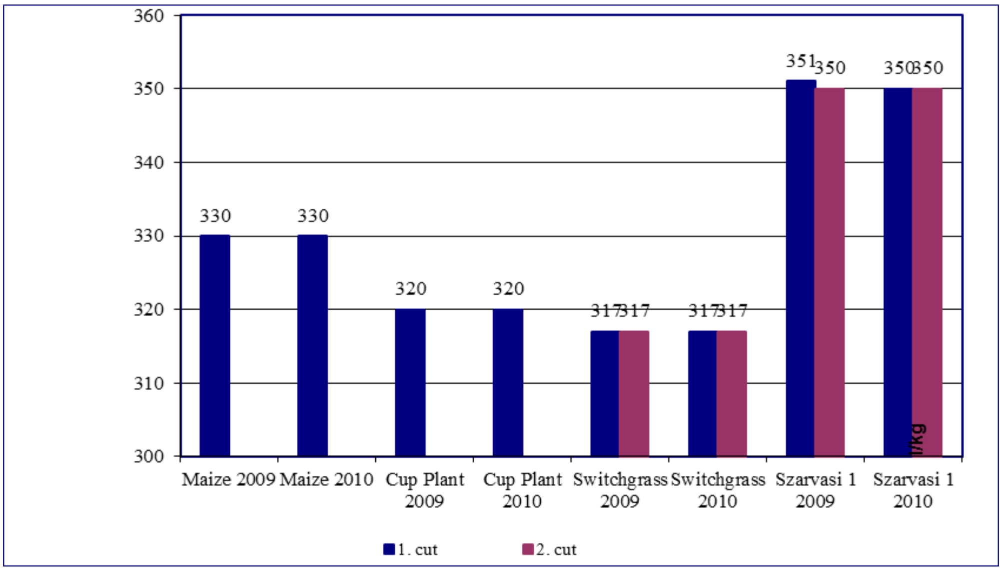
The best feature of energy grass ’Szarvasi-1’ is that it can also be successfully grown in low quality lands and under extreme weather conditions. This plant can be planned for 10- to 15-year cycles without reseeding, can be cultivated using normal cereal technology lines, and represents the cheapest solution among energy crops in terms of plantation costs. Energy grass ’Szarvasi-1’ can be efficiently used to produce biogas both in the green state and upon mixing with cattle and liquid manure. This property renders the plant the best additive for biogas production. The by-product of biogas production from energy grass or from a mixture of manure and energy grass is an excellent biomanure for soil fertilisation.

The increased demand for this plant resulted from the German paradigm shift regarding nuclear power plants, and as a consequence, academic research provided evidence that this plant may replace fodder crops (silo maize) in the feedstock supply to the energy sector, thus mitigating the difficulties in the feedstuff supply to animal rearing. In addition to the accessory role of processing animal manure in an atmosphere-friendly manner, large respiration surfaces may also be created in areas which were previously unsuitable for establishing agricultural cultivation.

9. **Experimental results proved that energy grass ’Szarvasi-1’ demonstrating a dry weight yield of 19.3 tons (in 2009) and 18.5 tons (in 2010) per hectare clearly surpasses maize (used as reference) and other energy grasses considered in this research. In 2009, this Hungarian energy grass produced 6 757 m^3 of methane per hectare, corresponding to a high methane output of approximately 350 l per kg dry weight; this represented the highest value in 2009 among all studied grasses and, a 38% yield superiority in comparison with maize. It may be concluded that the Hungarian energy grass ’Szarvasi-1’ demonstrated the highest performance in the current energy grass experiments.**

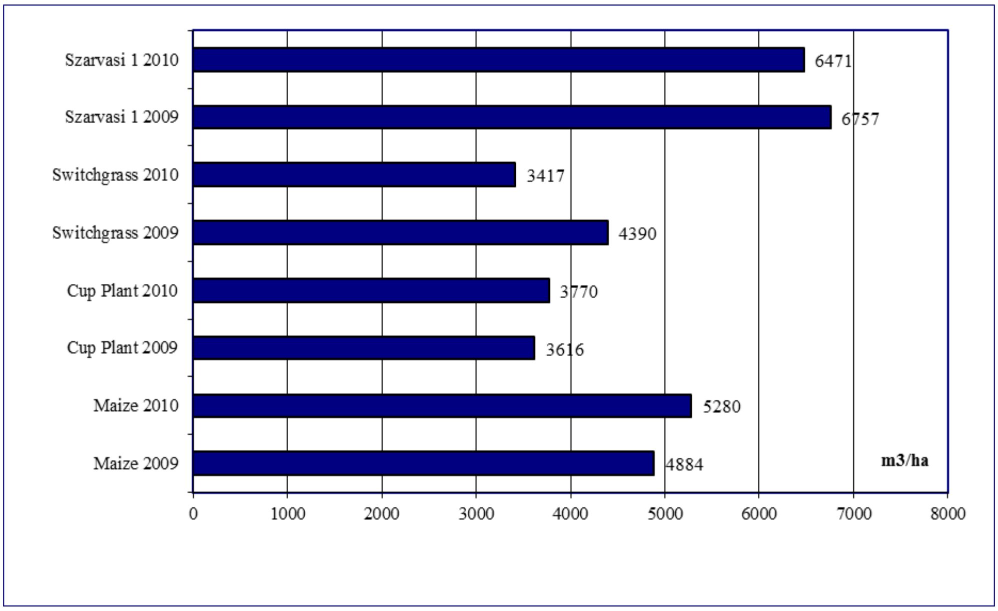
When evaluating plants that may represent alternative sources for biogas production plants, the key point was to emphasise currently unused cultures as main produces instead of the currently predominant maize, as these can offer a real potential alternative to the existing plant cultures while the production remains economically viable.

The reference properties of maize feedstocks which are – as an objective of the present research – to be replaced in the field of biogas production were compared to three plants suitable for energy generation (cup plant, switchgrass and energy grass ’Szarvasi-1’), which constitute the subjects of this study, and it was concluded that energy grass ’Szarvasi-1’ clearly exceeds the values of all three plants in terms of dry matter content, fresh mass weight, dry weight yield, methane output (Figure 1) and methane yield (Figure 2).



Source: LLA, 2011

Figure 1, Methane output between 2009 and 2010 (litre/kg)



Source: LLA, 2011

Figure 2, Methane yield in 2009 and 2010 (m^3/kg)

10. As regards major cities in the EU, the key problems in those which have launched compressed biomethane (CBG) projects include the high investment costs of biorefineries and the high costs of establishing the required infrastructure. Where CBG enjoys significant market penetration, problems are caused by an excess supply of vehicle models and an excess demand for biomethane.

There are a number of European examples for the use of biomethane in urban transport. I studied the examples of Lille, Rome, Stockholm and Gothenburg regarding their production and use of CBG.

In cities where biomethane is typically used in public transport, two basic approaches may be distinguished. Under to the project approach, a few CNG-based but biomethane-powered

vehicles are put into service in the framework of so-called ‘pilot’ projects. In cities following the network approach, long-term strategies are adopted to ensure that biomethane obtainable from municipal wastes and wastewater is used to power public transport vehicles and vehicles collecting municipal waste. In addition, the energy needs of people would also be satisfied and this would generate extra profit for the biomethane production plants.
In order to achieve a suitable level of market penetration for CBG/CNG, the governments provide nationwide subsidies to promote the use of vehicles powered by alternative fuels. These subsidies are equally available to private persons, companies and local municipalities.

Table 2 : Subsidies available for biomethane production and uses in European cities

Lille	Rome	Gothenburg and Stockholm
Exemption from vehicle tax in case of company cars	Subsidy for the purchase of green vehicles (EUR 1 500 to 3 000)	Free parking for green vehicles (this applies to all biofuels)
20% “green car” obligation for local municipalities	Reduction of the traffic jam fee, 50% discount in case of driving into protected zones	Reduced vehicle tax (40%) for CNG-powered company cars
Investment aid (50%) for reducing air pollution	Subsidy for the conversion of engines to CNG (EUR 650)	It is a general expectation that 75% of the vehicles used by the administration should be green vehicles
Tax exemption for CNG from the general tax of natural gas	20% reduction of the VAT for CNG fuels	Tax-free biomethane, and 40% discount from the VAT of CNG
Additional cost refunds for establishing emissions reduction schemes		State aids to vehicles, fuelling stations and biomethane production plants
Purchase aid for CNG vehicles, exemption from the registration tax		Positive discrimination in airport taxi services, “green car” aid (a one-time aid of EUR 1 100), and exemption from vehicle tax for 5 years in case of “green cars”

Source: PÄDAMS, et al., 2010

In view of the above, I evaluated Budapest in terms of its potential for using CBG/CNG. The emission levels and transport conditions in Budapest necessitate effective intervention and concrete actions.

11. Considering the experiences of some major European cities and the maintenance and fuel costs of the obsolete buses used in the public transport of Budapest, and by comparing the purchase, maintenance and fuel costs of buses powered by alternative fuels which can be used in public transport, it can be concluded that CNG- and biomethane-powered buses represent the cheapest and most environment-friendly solution for the capital city.

Hungary’s commitments for 2020 include a 10% share of biofuels from the total fuel consumption of the transport sector. Presently, biofuels are mixed to petrol and gasoline at a rate of 4.8% (v/v). The obligation to mix biofuels at significant ratios cannot be satisfied through personal cars because – on the one hand – the personal cars currently in use would not tolerate more than 10% of biofuels without a breakdown of the engine, and – on the other hand – the total quantity of biofuels consumed by personal cars would not be sufficient to achieve the target values. Therefore, it may be reasonable to upgrade the public transport and municipal waste collection systems of the city. This will require regional or local initiatives, as well as support for such initiatives.

Hence, I am assessing the economic and social benefits Budapest could enjoy by introducing biomethane-powered buses. I also address the purchase costs of CNG/CBG buses by comparing them to the purchase prices of conventional diesel-powered buses, and evaluate the maintenance costs of the current <E0 and E0 fleets. Based on the results of my calculations, I address the advantages of investing into CNG/CBG-powered buses, which may represent direct savings for the Budapest Transport Company (BKV) and indirect savings for the Municipality of the Budapest Capital City. The comparisons clearly indicate that the most economically viable short- and medium-term solution is to purchase CNG buses and to power them with biomethane, because

- although the purchase price of CNG buses is 8% higher than that of diesel-powered buses but
- in case of CNG and biomethane fuelling, the maintenance costs are 69% and 65% of those of diesel buses, respectively.

Besides economic viability, another advantage of CBG buses over diesel buses is that they are more environment-friendly, because CBG is associated with:

- no CO_2 emissions,
- no solid particle and SO_4 emissions,
- considerably lower CO and NO_x emissions than in the case of diesel,
- no heavy metal content,
- lower noise frequency and vibration levels than in diesel buses

12. Combining phytoextraction with energy generation – in case of a plant species, which is not only tolerant to pollutants but is also characterised by rapid growth and high biomass yields making it suitable for energy generation – is the most economical and efficient technology both in terms of decontamination and renewable green energy production. Energy grass ’Szarvasi-1’ – a Hungarian cultivar – easily satisfies these criteria.

In addition to food and feed safety concerns, another problem awaiting solution is environmental pollution. The sources of such pollution are various and include mining, industrial activities, transport, inappropriate use of artificial fertilisers, or the by-product of cities, i.e., wastewater. Tons of wastewater are generated, which are settled in wastewater treatment plants located in the vicinity of the cities and require proper disposal. In Hungary, the most widely used technique is agricultural application, which requires decontamination of the wastewater sludge using various expensive methods (e.g., chemical treatment). One method which may be cheaper than the chemical one is the decontamination of polluted soils using plants, i.e., by phytoextraction. Essentially, phytoextraction means making use of the capacity of plants to uptake elements from the soil at various rates. Moreover, soils may contain additional polluting elements (e.g., Pb, Cd, Cr, As, etc.), which may inhibit the

growth of the plant. However, certain plants such as energy grass ’Szarvasi-1’ are able to tolerate this and to accumulate one or more toxic substances during their development. Such plants are suitable for phytoextraction; that is, for removing polluting elements from the soil.
Upon summarising the results of the experiments conducted with energy grass ’Szarvasi-1’, it can be concluded that:

- Lead and zinc are tolerated by energy grass ’Szarvasi-1’, but cadmium and copper are not so much
- Pb accumulation is inducible by complex-forming substances
- Zn accumulation is reduced by EDTA and citrate
- Energy grass ’Szarvasi-1’ can be used to phytostabilise soils contaminated by lead or zinc, or by both.

13. The cultivation of energy grass ’Szarvasi-1’ on red mud ponds may simultaneously offer solutions to the phytoextraction of the area within a period of 10 to 15 years, the recultivation of the landfill, the treatment of municipal wastewater sludges – which are hazardous wastes –, and the economically viable production of feedstocks for renewable energy generation, while potentially creating a production basis with high and unique revenue generation capacities upon negligible expenditure, as well as jobs not requiring high levels of education.

It can be concluded that it is both a social need and an environmental obligation to neutralise the highly polluting substances in the red mud tailings ponds. The scientific experiments conducted with energy grass ’Szarvasi-1’ provided evidence that this plant is able to encapsulate toxic elements. Energy grass ’Szarvasi-1’ grown this way, and then harvested using simple mowers and baled can be sold for combustion applications.

Table 3 : Calorific value of energy grass ‘Szarvasi-1’ and some other energy carriers

Average efficiency of the combustion equipment (%)	**Fuel**		
	Type	**Calorific value (MJ/kg-MJ/m^3)**	
		Laboratory value	**Efficiency-adjusted value**
Coal-fired boiler (60)	Brown coal	13.9	8.3
Wood-fired boiler (65)	Firing wood (acacia)	14	9.1
Bale-fired boiler (55)	“Szarvasi-1” bale	14.9	8.2
Gas boiler (85)	Natural gas	34	28.9
Pellet-fired boiler (85)	“Szarvasi-1” pellet	17.2	14.6
Pellet-fired boiler (85)	Wood pellet	17.2	14.6

Source: Szarvasi Agricultural Research and Development Public Company, 2010

In addition to energy crop plantations for combustion purposes, other areas which cannot be used for production and require recultivation are also suitable for accepting non-composted wastewater sludges without additional costs, and this would also solve the issue of applying municipal wastewater sludges as fertilisers. Within the wastewater treatment technology, energy grass ’Szarvasi-1’ offers a suitable alternative to the step of agricultural application without composting, which offers quantifiable economic benefits for both producers and users

– in this case, to agriculture and to the wastewater sector –, and also represents environmental and social advantages for the country. The objective of this research into the possibilities of combining energy grass ’Szarvasi-1’ and municipal wastewater sludges is to provide the basis for a method of wastewater disposal and use, which would offer a cheap and final solution to the disposal of municipal wastewater sludges generated by residential areas, and all this in the vicinity of the point of generation without shipment to great distances, and under environment-friendly circumstances, through stimulating the growth of the plant and maximising the amount of wastewater sludge applied.

4. New and innovative scientific results

R1. Among the biofuels obtainable from biomass, the improvement and development potential of biogas exceeds that of bioethanol and biodiesel obtainable from first-generation food raw materials.

Besides the first-generation bioethanol and biodiesel, which have been regarded as critical in terms of food, energy and environmental safety, second- and third-generation biofuels, which are not produced from food raw materials, gradually appear. In addition, biogas obtainable from wastes, and used as an engine fuel besides bioethanol and biodiesel, is also gaining importance. Biogas is the only biomass product which is not in conflict with any interest groups or sectors, and does not represent a food safety hazard. The GHG emission reduction value of biogas (81%) by far exceeds that of the first-generation bioethanol (49%) or biodiesel (56%). Moreover, biogas (produced form energy grass ’Szarvasi-1’) is also superior to its first-generation competitor in terms of energy balance (5.5 to 15.6 vs. 1.2 to 8.3). Its parameters are also superior when used as an engine fuel, since greater distances can be run with biogas produced from maize than with bioethanol produced from maize.

R2. In connection with the measured biogas production characteristics of the currently popular maize (silo maize), which is the most widely used agricultural feedstock of biogas production, it may be concluded that – instead of maize – energy grass ’Szarvasi-1’ is able to offer an alternative solution to biogas production without representing food and feed safety hazards.

I evaluated the plants that may represent alternative sources for biogas production, during which the key point was to emphasise currently unused cultures instead of the currently predominant maize. I evaluated plants expected to ensure high and stable dry weight yields, and with methane contents and methane outputs that are suitable for biogas production. The four evaluated plants included cup plant, switchgrass, energy grass ’Szarvasi-1’, and maize as reference. As regards dry matter content, the measured values for energy grass ’Szarvasi-1’ and maize were 49% and 32%, respectively. Similar to maize, cup plant produces a high fresh mass weight, however future expectations can only be safely based on energy grass ’Szarvasi-1’. The lowest value for energy grass ’Szarvasi-1’ is 18.5 atrotonnes/hectare, while the best for maize was only 16 at/ha. As regards methane outputs, maize is only expected to produce 330 l/kg, while energy grass ’Szarvasi-1’ is expected to produce 350 l/kg making it clearly competitive also in comparison with the methane outputs of poultry manure. The methane yield of ’Szarvasi-1’ (6 471 and 6757 m^3/ha) clearly exceed that of maize and other energy crops.

R4. Based on my CBA analysis, I concluded that growing energy grass ’Szarvasi-1’ for the purpose of biogas production is expected to generate much higher profits than the benefits from agricultural investments into silo maize characterised by similar risks. With this, I prove my initial hypothesis **that the feedstock demand of the developing biogas sector** requires ever **increasing quantities** of feedstocks **that can be safely produced; therefore, the production of energy grass ’Szarvasi-1’ as a feedstock for biogas production under the current market circumstances would be a profitable activity in the medium and long term**.

In Hungary, the mandatory 10% level of renewable energy uses to be achieved by 2020 in road transport could be reached by the use of biomethane fuels besides bioethanol and biodiesel. The currently most widely used biogas production feedstock, animal manure, cannot safely satisfy the increasing feedstock demands of the biogas production plants on its own. Plant wastes or dedicated energy crops need to be added. Since energy grass 'Szarvasi-1' proved to be the best in the analysis of plant-based feedstocks, I considered it necessary to also assess the economic viability of its cultivation and to compare it with that of the popular silo maize. Among the economic methods, I chose the cost-benefit analysis (CBA) of production, which was based on cost items from relevant Hungarian cultivation efforts financed from own funds. I modelled the net current value of the cultivating energy grass and silo maize projected for a 10-year period. Based on my CBA analysis, the net current value of the 10-year projected investments into cultivating energy grass 'Szarvasi-1' for the purpose of biogas production, that is, the sum of the discounted net cash flows calculated for the analysis period is EUR 1 055 232. For silo maize, the net current value calculated for a 10-year period is EUR 753 993. Thus, energy grass is expected to generate much higher profits than those originating from agricultural investments with similar risk levels. The payback period of the invested base-year cost of cultivating energy grass over an area of 1 000 hectares is a little more than 5 years.

In summary, the results of the calculations indicate that cultivating energy grass 'Szarvasi-1' on lower quality soils and with less expenditure results in higher quantities of biogas feedstock with higher gas yields than from the currently applied silo maize.

R5. Biomethane obtainable from biogas is clearly the most promising solution for the upgrading of public transport.

The direction of development for bus fleets involved in urban and suburban transport is towards a widespread use CBG-powering instead of diesel-powered buses. However, this requires medium- and long-term thinking in addition to project-based approaches. Such capital-intensive investment projects (biogas production plant, purifier, filling stations, and purchase of buses) could only be implemented in an economically viable manner if the members of the network of Budapest are mostly public utility companies with a business interest area in the capital city in order to guarantee fuel production and use through long-term agreements between them. If co-financed by the EU, such a project could receive 85% subsidisation on all eligible costs in 2013 had the Municipality of the Capital City formed a consortium with the Central Wastewater Treatment Plant of Budapest (BKSZT) and the Budapest Transport Centre (BKK). Similar aid intensities are foreseen in the next programming and budget period (2014-2020) as well. Therefore, an investment of this order of magnitude may pay back within 3 to 4 years.

R6. Energy grass 'Szarvasi-1' can be used to decontaminate wastewater sludges and the red muds stored in the red mud tailings ponds of Ajka.

Among the environmental contamination concerns, the disposal and landfilling of municipal wastewater sludges is one of the major issues of our age awaiting solution. Since wastewater sludges contain various levels of polluting and nutrient elements, toxic pollutants should be removed. This is facilitated by phytoextraction, which means making use of the capacity of plants to uptake elements from the soil at various rates, but the key point is harvestibility. Combining phytoextraction with energy generation is the most economical and efficient technology both in terms of decontamination and renewable green energy production. Therefore, we conducted experiments with energy grass 'Szarvasi-1' to assess the changes in the physiological properties of the plant upon treatment with one or more heavy metals. I concluded that lead and zinc are tolerated by energy grass 'Szarvasi-1', but cadmium and copper are not so much; that Pb accumulation is inducible by complex-forming substances;

that Zn accumulation is reduced by EDTA and citrate; and that energy grass ’Szarvasi-1’ can be used to phytostabilise soils contaminated by lead or zinc, or by both. This way, I proved that energy grass ’Szarvasi-1’ can be used to decontaminate wastewater sludges and the red muds stored in the red mud tailings ponds of Ajka. I also conducted economic viability and sensitivity analyses with a view to using the grass for combustion and environmental purposes. I concluded that the factors which most markedly influence the payback period of the investment include price changes in agricultural services, and the fees of the agricultural application of wastewater sludges.

5. Conclusions and recommendations

Upon summarising the results of my research, it can be concluded that integrated political, social and economic efforts are required to mitigate the effects of climate change. As a result of increasing social pressure and attempts to enhance economic viability, renewable energy carriers have become the subject of focus. Regions with different features may exploit different renewable energy sources. The question is : how to use environment-friendly and efficiently renewing energy sources to gradually replace fossil fuels in the cheapest way?

In Hungary, rising energy prices and the energy dependence of the country stimulates us to make use of our capabilities and generate renewable energy sources from biomass. The current contradictory, non-complex and anti-subsidisation legal environmental, and the deficiencies of the technology do not support the generation and feeding of renewable energy into the network. Experience shows that today, biomass-based renewable energy generation in Hungary is only economically viable if the energy thus generated can be used locally.

As a result of my comparative analyses, I concluded that compliance with the biofuel commitments of the country is dubious despite the fact that Hungary has appropriate quantities of feedstock of appropriate quality. In my opinion, we will not be able to meet the target values for bioethanol at all by 2020, and we might only be likely to meet those for biodiesel. Our commitments regarding biomethane as fuel are minimal although the potential of CBG fuels has been exploited with outstanding success in several countries of Western Europe. Since the feedstock of first-generation biofuels is typically a food crop, there is a justifiable need for other alternative feedstocks that could replace food crops (chiefly, maize and oilseed crops). Based on my research and comparative analyses, I concluded that among the plants capable of replacing maize, the measured useful biogas production parameters of energy grass 'Szarvasi-1' are higher or occasionally much higher than those of maize. In can be concluded that taking into account agro-ecological, environmental, soil use, energy generation and economic viability considerations, the agronomic, energy generation and industrial properties of energy grass 'Szarvasi-1' are highly promising and several aspects of it are also unique in comparison with other plants suitable for this purpose. Since extreme cultivation site conditions and unfavourable areas with salt-water stagnation are well tolerated by this grass variety, I extended my research to include an assessment as to whether this grass can also be used for soil recultivation purposes. The results indicate that this grass variety is highly useful for the reasonable utilisation and improvement of not only saline and sand soils but also of wastewater sludge-contaminated areas, thus offering a solution to the problems of protecting the environment and generating renewable energy.

As regards the urban use of biofuels, we have several deficiencies which are primarily infrastructural in nature but also originate from the lack of incentives and strategic approaches. Today, the future is towards the urban use of CNG vehicles (personal cars, and buses) and biomethane (CBG). However, this would require biomethane production in Budapest. The biomethane could be purified in sufficient quantities by the Sewage Works of the Capital City (FCSM) or the Central Wastewater Treatment Plant of Budapest (BKSZT). Therefore, it is reasonable to consider to use the useful substances present in the sludge in an environment-friendly manner than to apply them to lands or deposit them in landfills at significant extra shipment and application costs. Thus, a scheme of incentives should be developed. In case of economically viable solutions (e.g., putrefaction), it would be justifiable to use the organic substances in the sludge for the purpose of secondary energy generation (heat and electricity generation) or to produce biomethane, which can be used in public transport upon purification. The scientific experiments conducted with energy grass 'Szarvasi-

1’ provided evidence that this plant is able to significantly increase the methane content of the raw biogas when admixed to wastewater sludge thus guaranteeing a CH_4 content of >97% in the fuel.

The disposal and economically viable treatment of wastewater sludges represent a constant problem for wastewater treatment plants. Experimental plantations at the site of the unfortunate catastrophe of the red mud tailings ponds of Ajka clearly demonstrate that energy grass ’Szarvasi-1’ is capable of decontaminating the heavy metals in the red mud; therefore, wastewater sludges can be applied at lower costs and at higher efficiency in other areas unsuitable for agricultural plantations than in the case of agricultural application.

6. Curriculum vitae

Gyula Sipos started his university studies under the degree course of Business Agro-engineering at the “Georgikon” Faculty of Agronomy of the University of Veszprém in Veszprém in September 2001, and was later admitted to the degree course of Business Economics at the Faculty of Economics and Social Sciences of “Szent István” University, and graduated in 2006 as a business agro-engineer. During his university years, he studied marketing strategies for genetically modified foods in Washington, Baltimore and New York in 2004, with a scholarship from the United States.

Upon graduating, he was admitted to the Management and Business Administration PhD School of “Szent István” University as a regular student. His duties included lecturing and research at the university, and presented the results of his research projects at important international conferences. During this period, he played an important role in establishing the renewable energy strategy of Hungary as a project coordinator of the Ministry of Agriculture and Rural Development through synthesising and checking of the documents received, and conducting the related analyses.

Between 2006 and 2010, he pursued training activities as an external lecturer at “Szent István” University and at “Szent István” High School (Budapest), teaching about issues related to the Common Agricultural Policy and the potential opportunities of renewable energy generation. On several occasions, he acted as a member of conference organisation committees, or as an adjudicator.

In 2007, he was employed by the Central Transdanubian Region Branch of OTP Bank as the sales consultant of the regional director. Because of this job, he became a corresponding student of the PhD School. In 2008, he became a consultant of the central Department of Credit Risk Control of OTP Bank, where he established uniform risk management rules for the acquired areas (Eastern European area) while resolving the differences originating from the relevant arrangements in these countries.

In 2009, he established and founded GVSX Kft. (GVSX Ltd.), and pursued consultancy and technical product development as an owner of the company. He and his team of developers are credited with the creation of a number of innovative products. During the same period, he became the managing director – and subsequently, a co-owner – of Bikazugi Mezőgazdasági Nonprofit Kft. (Bikazugi Agricultural Nonprofit Ltd). The key activities of this nonprofit company include production and selling of energy crops. To make good use of his knowledge and opportunities, he conducts experiments and development tasks in connection with the processing and use of energy crops.

In his PhD dissertation, he presents the potential multiple uses of energy grass ’Szarvasi-1’, and he is expected to defend it in 2014.

He has a Type C (oral and written) intermediate-level language examination certificate in German, and a basic- and intermediate-level language examination certificates in English.

His publications include 5 Hungarian or non-Hungarian scientific articles, 6 Hungarian or non-Hungarian presentations at scientific conferences, and 3 Hungarian articles published in other journals.

7. List of publications

Scientific journals (scientific articles published in Hungarian, scientific articles published in other languages) :

1. Sipos, Gy. (2014): A biogáz-termelés növényi alapanyagainak összehasonlító elemzése Gazdálkodás˙(“A comparative analysis of plant-based feedstocks of biogas production”), (statement of acceptance enclosed)
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3. Sipos, Gy., Somogyi, A. (2008): The challenges of EU communication 3 years before the Hungarian Presidency, *Studies in Agricultural Economics*, No. 108, pp. 33-46, ISSN 1418-2106
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11. Sipos, Gy., Fodor, F., Vashegyi, I. (2012): Szarvasi-1 Energy Grass combining bioenergy production with phytoremediation, 4th International Energy Farming Congress: 13-15 March, 2012. Papenburg (Germany), Book of Abstracts, p. 20

Other journals

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